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ALIGNMENT IN GAMMA-HADRON FAMILIES OF COSMIC RAYS

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Abstract

Alignment of main fluxes of energy in a target plane is found in families of cosmic ray particles detected in deep lead X-ray chambers. The fraction of events with alignment is unexpectedly large for families with high energy and large number of hadrons. This can be considered as evidence for the existence of coplanar scattering of secondary particles in interaction of particles with superhigh energy, $E_0 \gtrsim 10^{16}$ eV.

Data analysis suggests that production of most aligned groups occurs low above the chamber and is characterized by a coplanar scattering and quasiscaling spectrum of secondaries in the fragmentation region.

The most elaborated hypothesis for explanation of alignment is related to the quark-gluon string rupture. However, the problem of theoretical interpretation of our results still remains open.

1 Introduction

International Pamir Collaboration is conducting a cosmic ray experiment at the altitude 4400 meters above sea level in Pamir mountains. Primary cosmic ray particles incident upon atmosphere produce nuclear-electromagnetic cascades of secondaries in air. Hadrons and electromagnetic particles related genealogically are called "family". Gamma-hadron family features depend on interaction of hadrons with nuclei in air.

Experimental data accumulated during more than 20 past years may allow us to study interactions at very high energy (up to $E_0 \sim 10^{16}$). These energies are beyond the present accelerator range, and new phenomena may reveal themselves in this region.

1.1 Installation

Pamir Experiment equipment consists of X-ray emulsion chambers of two kinds: carbon chambers (C-chambers) and deep lead chambers (Pb-chambers).

Pb-chambers (see Fig.1) are assembled of many sheets of lead of thickness 1 cm, interlaid with X-ray films. The total depth of each Pb-chamber is from 40 cm (≈70 c.u.) up to 110 cm (≈195 c.u.). Thick lead substance provides both few interaction lengths for hadrons and quasicalorimeter regime for energy determination of particles.

C-chamber [1] consists of a block of 60 cm of carbon covered on both sides by blocks of lead of thickness 6 cm at the top and 5 cm at the bottom. Each block of lead contains 3 layers of X-ray film. Carbon block provides the large cross section of hadron interaction, while lead blocks are of minimal thickness allowing determination of particle energies.

Total area of chambers is few tens of square meters. Once a year all these chambers are disassembled, the films are taken away and the results of the experiment are investigated. The results to be reported in this paper have been obtained by using deep Pb-chambers, which have some advantages in hadron detection efficiency and energy determination accuracy. On the other hand, C-chambers possess larger area of exposure. Comparison with some data from carbon chambers is shown here too.

1.2 Experimental procedure

Cosmic ray gamma-quanta and hadrons create electron-photon cascades (or showers) in the lead. (The term "gamma-quantum" is conventionally used for both gamma-quanta and electrons (positrons)). These showers are detected in the X-ray emulsion film as dark spots of a size

which is typically smaller than 1mm.

The darkness density $D(E,t)$ of each spot depends on energy E of the cascade and on the depth t of its development in a chamber. Comparing $D(E,t)$ for every shower with theoretical predictions one can obtain the energy of each cascade and, consequently, the energy E_γ of a gamma-quantum incident upon a chamber and producing this shower in it. By doing so for hadrons, one can determine the energy $E_h^{(\gamma)}$ released into electromagnetic component within the installation. It differs from the hadron energy E_h^0 at the chamber surface by the factor k_γ being around 1/3 for pions.

Gamma-quanta produce electron-photon cascades in the upper part of a chamber only, whereas hadrons produce such showers at large depth as well. The criterion for hadron identification in families is that the breakthrough of a particle in a chamber (i.e. the shift of the origin of the cascade curve) has to be greater than 6 c.u. In this case only few per cents of admixture of misidentified gamma quanta are present among particles classified as hadrons.

Efficiency of hadron detection is about 70-80 % in average for Pb-chambers, and about 55 % for C-chambers.

All chambers have energy determination threshold around 4 TeV for E_γ and $E_h^{(\gamma)}$ (or around 12 TeV for E_h^0 correspondingly).

While dealing with gamma-hadron families one can reconstruct the target diagram of an event by measurement of coordinates and incidence directions of particles in the film emulsion. Thus one can find such characteristics of a family as the total energy of gamma-quanta ΣE_γ or the total energy of hadrons released to gamma-quanta $\Sigma E_h^{(\gamma)}$, the distributions of gamma-quanta and hadrons in the event area, E_γ or $E_h^{(\gamma)}$ spectra, etc. All families in our experiment were classified by the value of the total energy of the gamma-component ΣE_γ. Families with $\Sigma E_\gamma \geq 100$ TeV are under consideration here. When studying "superfamilies" with $\Sigma E_\gamma \geq 1000$ TeV it was found that in the central region of the event one can often see one or few large diffuse dark spots (halos) in the X-ray films, of a size from several millimeters up to few centimeters. Each such halo appeared usually as a result of development of an atmospheric electron-photon cascade from a high energy gamma-quantum produced at some altitude above the chamber [2, 3].

In the lower part of a deep lead chamber one can also find large spots looking like small halo, but having hadronic origin [4]. Each such halo is a result of a cascade produced by a hadron of a very high energy in lead (with $E_h^{(\gamma)}$ about 200–500 TeV).

1.3 History and formulation of the problem

In 1985 Pamir Collaboration has found several families with 3 or 4 halos of electromagnetic origin [5, 6], and in most of these families (in 5 out of 6 such families) the multiple halos were aligned more or less along a straight line. Experimental results obtained during the subsequent years did not increase considerably statistics for investigation of such events, but the relative fraction of events with aligned multiple haloes of electromagnetic origin became smaller.

As an alignment criterion the parameter of asymmetry introduced by A.S.Borisov [7] is conventionally used:

$$\lambda_m = \frac{\sum\limits_{i \neq j \neq k = 1}^{m} cos2\varphi_{ijk}}{m(m-1)(m-2)} \ . \tag{1}$$

Here m is the number of objects, i, j, k stand for vertices, φ_{ijk} is the angle between two vectors $\overline{ki}$ and $\overline{kj}$. An event is considered as aligned one if $\lambda \geq 0.6$. (A stronger requirement is $\lambda \geq 0.8$).

Parameter λ_m is the best known parameter of asymmetry describing the degree of alignment rather than eccentricity. For example, λ_4 will be equal 1 if four points belong to the same straight line, but it will be far less than 1 if these points form four vertices of a long rectangle.

To have a grasp of fluctuation background, i.e. the probability of random occurrence of alignment while the development of nuclear-electromagnetic cascade, a computer simulation of families with multiple halos was made [8, 9] using a quasiscaling model without any specific mechanisms for producing asymmetry [10]. Relative fraction of events with three aligned halos in the simulated families appeared to be rather high, about 30-35 % (by the criterion $\lambda_3 \geq 0.6$).

The level of background noise calculated for 3 random incident points (or "particles" not belonging to the same cascade) was given by 24 % by the same criterion. Therefore the appropriate analysis of the phenomenon to isolate the effect from fluctuation background became essential.

However in the works [5, 6] discussed above only halos at the same (small) depth in the upper part of C-chambers were considered under some constraint on the level of darkness D of the spots in X-ray films. Experimental results obtained in Pb-chambers allowed to investigate alignment of multiple halos at different observation depths and at various levels of darkness D, and to take into account the contribution of hadron cascades (hadronic halos) in the lower part of a chamber [8]. It was found that the alignment of multiple halos in the same family is a function of both the depth and the level of darkness D used for halo identification. Therefore this approach seems physically inadequate.

It is worth mentioning here that an attempt to investigate asymmetry of family particles configuration (separately for gamma-component and for hadrons) in events of small energies (ΣE_γ = 100–400 TeV) was made in [11]. It was found that there was some excess of asymmetry in experimental events over simulated ones. However, analysis was carried out with a quite

different criterion of asymmetry α, and the existence of such asymmetry did not necessarily imply alignment.

In the investigation of alignment we tried to find a better method of selection of objects to be examined, which would be more sensitive and less dependent on methodological factors. In [9, 12] it was suggested to consider not only halos, but a more general class of objects, which was called "Energy Distinguish Cores" (EDC). These objects in the X-ray film correspond to the centers of the most prominent jets (air cascade branches) with the highest energies in a family. They include the following objects:

a) halos of the electromagnetic origin (or separate cores of a multiple halo);

b) gamma-clusters (i.e. compact groups of gamma-quanta which are combined into clusters using the criterion of decascading);

c) separate gamma-quanta of high energy;

d) high energy hadrons (in particular, the hadrons which produced halos in the chamber).

In order to treat gamma-component and hadrons in a similar way, one should multiply by the factor of 3 the energy $E_h^{(\gamma)}$ released by a hadron in the chamber into the electromagnetic component, since the most secondaries in a family are pions and the average fraction of energy transferred by pions to the electromagnetic component is approximately equal to 1/3.

All energy distinguished cores (EDC) are considered in the order of decreasing energy, so it becomes clear how to select 3 or more objects in each family for analysis.

This approach allows to study alignment in gamma-hadron families of not very high energies when there are no halos, and to avoid discrimination of some types of EDC against some other ones. By this method the investigation became effective and physically equivalent for both charged secondaries in an atmospheric shower (family hadrons) and neutral secondaries (gamma-component in the same family), combining them to describe the interaction above a chamber.

To investigate alignment of all family cores, which are detected at different depths in the chamber, a target diagram was made by projecting all traces of EDC onto one plane (for example, onto the plane of the chamber top surface). If the zenith angle of an event was not zero, the family image was transformed to normal plane. Alignment of the energy distinguished cores was studied in this plane, see e.g. Fig. 2.

2 Results

2.1 Experimental statistics

In this work we have analyzed 68 gamma-hadron families from deep lead chambers with total energy of gamma-component $\Sigma E_\gamma \geq 100$ Tev, number of gamma-quanta $N_\gamma \geq 3$ and number of hadrons $N_h \geq 1$ (see Table 1). In our data bank there are also 19 families with $N_h = 0$ which were not used in this work, since we were looking only for gamma-hadron families. Among these 68 events there are 18 families with $\Sigma E_\gamma \geq 500$ TeV, see Table 2. (Such high energy events were collected from larger area of installation than lower energy ones.) Total exposure of Pb-chambers here in use is about 450 m^2·year. As for the hadron component, 13 events with $N_h > 10$ are present in our data.

For comparison in some figures we also show the data from carbon chambers of Pamir Russia-Japan Joint Experiment. This set contains 84 gamma-hadron families with $\Sigma E_\gamma = 100 - 2600$ TeV (see Table 1) from total exposure around 440 m^2·year. These results were obtained using Japanese X-ray films from Pamir chambers measured in Waseda University (Tokyo) and analyzed with participation of the authors.

2.2 Evidence of alignment

To find the effective criteria of alignment for analysis, we tested various threshold values of λ and variants including different numbers of cores (EDC) in a family. The best ratio of the signal to the fluctuation background with satisfactory statistics appears with the alignment criterion $\lambda_4 \geq 0.8$. However, versions with other numbers of EDC are also shown in our figures.

The proposed approach allows to follow behavior of the fraction of events with alignment as a function of ΣE_γ, representing the family energy.

In Fig. 3(a,b,c) one can see such dependence for correspondingly 3, 4 and 5 energy distinguished cores selected in each family in order of decreasing energy. Two dashed lines in each figure show levels of accidental occurrence of alignment in model simulations (i.e. in artificial gamma-hadron families) and in simulated groups of randomly incident objects. One can see that fluctuation background level is always higher in model events due to correlations in a cascade. The model which we have used [10] does not involve any special mechanism of asymmetry. Hereafter the criterion $\lambda \geq 0.8$ is used for classification of the families with alignment.

The increase of the fraction of events with alignment is evident for families studied in deep lead chambers. This fraction rises from the background level at $\Sigma E_\gamma =$ 100–300 TeV to $(61\pm18)\%$ for 3 cores under consideration and to $(47 \pm 17)\%$ for 4 EDC at $\Sigma E_\gamma \geq 500$ TeV.

It is worth noting that an additional analysis has been performed, where we have studied the behavior of an alignment fraction with energy when various kinds of energy distinguished cores

were considered separately. According to this analysis, the fraction of events with alignment appeared to be independent of energy for gamma-quanta under consideration, but increasing with energy for both gamma-clusters and hadrons. However, the increase of alignment with energy for gamma-clusters or hadrons is less prominent than the similar rise for EDC, where these two kinds of objects are included into consideration altogether with halos and gamma-quanta.

Such behavior of different kinds of energy distinguished cores confirms indirectly our understanding of the role of every component of a family in the alignment phenomenon.

The data obtained in the carbon chambers, Fig. 3, show the same tendency as the data obtained in the lead ones, but the increase of alignment effect for C-chamber data is somewhat less prominent. There may be few reasons for this difference. The data from C-chambers for maximal energy range are poor in the high energy events as compared with Pb-chambers. Besides that, the hadron detection efficiency for C-chambers is considerably lower than for Pb-chambers, and missed hadrons may destroy the display of alignment under consideration.

In Fig. 3b one can see the estimated value of the fraction of events with alignment if the thickness of lead chambers were be equivalent to the thickness of the carbon ones. This value seems to be in agreement with C-chambers data. The accuracy of energy determination for hadrons in carbon chambers (especially for high energy particles) is also lower than in Pb-chambers, where the multilayer method allows to follow a complete cascade curve from a particle in contrast to only one or two points over a lead block in carbon chambers.

The existence of the alignment effect is supported by the fact that the experimental point at $\Sigma E_\gamma \geq 500$ TeV (see Fig.3b) stays at two standard deviations above the fluctuation background level. If we estimate the combined significance of deviation from the background for 2 independent points at $\Sigma E_\gamma = 300$–500 TeV and $\Sigma E_\gamma \geq 500$ TeV, the χ^2-criterion yields the confident level $\simeq 99\%$.

Our model simulations of gamma-hadron families [13] showed that the best correlation with the primary energy E_0 of the air cascade is obtained not for ΣE_γ (or for $\Sigma E_{total} = \Sigma E_\gamma + \Sigma E_h^{(\gamma)}$) but for the number of hadrons in a family, N_h. Fluctuations of N_h at fixed E_0 appeared to be 2 or 3 times less than fluctuations of the total gamma-component energy ΣE_γ or total hadron energy $\Sigma E_h^{(\gamma)}$ for the same E_0. Therefore, if the effect under consideration has energy threshold while E_0 increases, the same behavior should be observed as a function of hadron number N_h, the increase of alignment being even more distinct than while considering dependence on ΣE_γ.

In Fig. 4 the dependence of the fraction of events with alignment on the hadron number N_h in a family is presented for various numbers of energy distinguished cores under consideration. One can see evident rise of the fraction with an increase of N_h. Thus the results presented in Fig. 4 confirm sensitivity of alignment to the number of hadrons in a family. In Pb-chambers the fraction of families with alignment comes to $(83 \pm 37)\%$ for 3 EDC and $(67 \pm 33)\%$ for 4 EDC. The increase of the effect for events from carbon chambers is in agreement with the Pb-chambers

data. C-chamber families are poor in events with large numbers of hadrons. Our comments on the carbon chambers data shown in Fig. 3 are valid for this comparison too.

Fig.5 shows the dependence of the fraction of families with alignment on the number of energy distinguished cores in each family under investigation. One can see that in families with $N_h = 1-3$ it is not higher than the level of fluctuation background, whereas for the group of events with $N_h > 30$ this fraction is much greater than the calculated background up to 7 cores considered. Despite large statistical errors, this makes an impressive case in favour of reality and significance of the effect under consideration, of its sufficiently high frequency of occurrence in the range of large N_h and, consequently, of high energies of primary particle E_0. The energy scale E_0 where we see a considerable alignment begins at about 10^{16} eV.

Fig. 5 also shows the fraction of aligned events in accelerator data at $E_0 = 250$ GeV (target experiment NA22 at CERN, π-Au interaction [14]). These results are in a remarkable agreement with the results of our model simulations of the background level. This confirms the methods which we have used in our simulations, as well as our conclusion that alignment is a threshold effect which occurs only at sufficiently large energies.

2.3 Transverse momenta of energy distinguished cores.

The analysis of transverse momenta p_t of EDC seems to be of importance in theoretical explanation of the phenomenon. It is well known that X-emulsion chambers detecting air families are able to measure not p_t itself, but a roughly related quantity ER (where E is the particle energy, R is the distance in the target plane from an axis). Relation between p_t and ER is based on the assumption that the particles are produced in one interaction at some altitude H above an installation. In this case $p_t H = ER$. ER of each core is determined in reference to the energy-weighed center of the group of 4 EDC in each family. Events with $\Sigma E_\gamma \geq 500$ TeV were analysed. Average value $< ER >$ in this case appeared to be 2.1 ± 0.8 GeV$\cdot$ km for events with alignment and 1.8 ± 0.5 GeV$\cdot$km for families without alignment. One cannot see any significant difference in this quantity between two classes of events.

It seems reasonable also to calculate the average ratio of longitudinal $p_t^{\|}$ and transverse $p_t^{\perp}$ (in reference to the alignment direction in the target diagram plane) in the same events for the same 4 EDC in each. Such quantity

$$\Sigma p_t^{\|} / \Sigma p_t^{\perp} = \Sigma E R^{\|} / \Sigma E R^{\perp} \tag{2}$$

is similar to the famous parameter "thrust". The average value $< \Sigma p_t^{\|} / \Sigma p_t^{\perp} >$ was obtained to be ~ 11 for events with alignment and ~ 4 for ones without alignment. This ratio differs considerably for the two cases. This is a natural consequence of separation by the criterion $\lambda \geq 0.8$. Such evaluation for events with alignment enables us to see that aligned cores come out of complanarity plane by $< p_t^{\perp} > \sim 0.1 < p_t >$.

Thus assuming the most probable interaction altitude $H = 2$ km (that follows from the halo superfamilies analysis [4]), $< p_t >$ within the group of 4 EDC is estimated as ~ 1 GeV/c and $< p_t^{\perp} > \approx 0.1$ GeV/c.

2.4 Energy distribution over the most energetic cores in a family

Energy distribution over 4 energy distinguished cores in each family is another interesting characteristic. Fig. 6 shows the distributions in energy fraction $E_i^{EDC}/\sum_{i=1}^{4} E_i^{EDC}$ for simulated families (quasiscaling MSF-model [10]) in energy ranges $\Sigma E_\gamma = 100$–500 TeV and $\Sigma E_\gamma > 500$ TeV and for experimental families in the same ranges. The shape of the distribution does not change with energy ΣE_γ in simulated families, and the shape of the distribution for low energy experimental families agrees with simulations, whereas the plotted points for superfamilies ($\Sigma E_\gamma > 500$ TeV) considerably differ from both above mentioned distributions.

In this representation the steeper the function falls with energy, the harder the energy spectrum of objects under consideration is. Solid line shows the distribution in energy fractions over the most energetic 4 particles produced in a direct interaction in quasiscaling model at $E_0 = 10^{15}$ eV. It is evident that the distribution for events with $\Sigma E_\gamma > 500$ TeV is close to the calculated one for particles just after an interaction in the quasiscaling model.

This shows that by investigation of the energy distinguished cores in experiment we in fact study the fragmentation part of the particle production spectrum, this part of the spectrum being only slightly distorted by the air cascade and by the detecting device.

In addition, this implies that the most energetic cores in the majority of the superfamilies under consideration are produced in one interaction at relatively low altitude above the chamber. (Particles coming from a big altitude might undergo a strong cascade affect).

3 Discussion

Alignment of energy distinguished cores (or particle streams, or energy fluxes) in air families should be related to a coplanar scattering in nuclear interactions. It is very hard to explain the results of our experiment in the framework of conventional interaction models. It can be inferred from [15] that the magnetic field of the Earth could not be responsible for any appreciable asymmetry. In the same work the obvious fact that the coplanar “fan” of particle streams may be blurred by cascade process after few interaction paths was confirmed by model simulation. Therefore, either the interaction which leads to the coplanar scattering occurs not far from the chamber, or it may occur more than few hadron interaction lengths above the chamber. However,

in the last case the multiplicity of aligned particles in this "fan" should be large enough to provide the alignment of 4 cores at the observation level while other originally aligned particles drop out of the original "fan" plane due to the cascade development.

There are two main problems which should be solved in order to find a theoretical explanation of alignment. First of all, one should identify an interaction mechanism, and then one should solve the problem of intensity of coplanar events. In the absence of a simple theoretical interpretation of alignment, any guess on the possible interaction mechanism should be carefully considered.

F.Halzen and D.Morris proposed an explanation of aligned multiple halos based on the semi-hard jet model ($p_t > 3$ GeV) [16]. Such an interpretation does not seem quite satisfactory because of the difference in the energy distribution of the main streams (jet particles have too low energy).

I.Roizen has suggested to interpret the phenomenon as a projection of quark-gluon string rupture produced in the process of semi-hard double inelastic diffraction dissociation, the string being inclined between a semi-hard scattered fast quark and the incident hadron remnants [17]. Such explanation seems plausible because the energy threshold of the alignment effect is consistent with the threshold-like dependence of semi-hard double inelastic diffraction. The "length" of aligned groups of EDC as a projection is also more or less in agreement with the transferred momentum while string production ($Q_t \simeq 3$ GeV/c). In this case the target diagram of a superfamily with alignment may be considered as a direct "photographic" image of such process.

Average invariant mass M of the entire group of 4 aligned particles is $< M^2 >= (60^{+120}_{-60}) GeV^2$. For the group of 6 aligned particles $< M^2 >= (150 \pm 150) GeV^2$. Such evaluation of M is again more or less compatible with inelastic diffraction picture [17].

Note that the energy range $E_0 \simeq 10^{15} - 10^{16}$ eV is proclaimed as the threshold for several unusual processes: a) for alignment phenomenon; b) for "Centauro" events production [18]; c) for explanation of electromagnetic particles spectrum in extensive air showers in experiment "Hadron" [19] ; d) for semi-hard double inelastic diffraction.

Possible relation of alignment to the string rupture hypothesis has been already mentioned above. It is pertinent to add that the ratio $\frac{<p_t^{\perp}>}{<p_t^{\parallel}>} \sim 0.1$ within EDC group is roughly consistent with proper string parameters in transverse momentum space, but as our preliminary model simulations show, it may be appropriate to assume very small $< p_t^{\perp} > \sim 20$ MeV across the string in order to explain of alignment. Such value has something in common with features of the hypothetical "Chiron" events production [20] suggested to appear in the same energy range.

The authors understand that the ideas discussed above do not constitute a complete theoretical interpretation of alignment. However, any hint can be important when discussing events at such a high energy and with such a hard-to-reach statistics. Active search for satisfactory explanation is necessary and is under way.

It would be most desirable to test this effect on accelerators. Preliminary estimates indicate that the energies accessible at FNAL would be barely enough to produce comparable families. However, one can still obtain interesting results at these energies due to the possibility of having much better statistics than in cosmic rays.

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Table 1

Experimental events in use: the number of gamma-hadron families with $\sum E_\gamma \geq 100$ TeV, $N_\gamma \geq 3$ and $N_h \geq 1$.

$\sum E_\gamma$ [TeV]	100–300	300–500	> 500	Total
Pb-chambers	35	15	18	68
C-chambers (Rus.-Jap.)	57	12	15	84

Table 2

Families from deep lead X-ray chambers with $\sum E_\gamma \geq 500$ TeV or $N_h > 10$.

Name of event	N_γ	$\sum E_\gamma$ [TeV] $E_\gamma \geq 4$ TeV	N_h	$\sum E_h^{(\gamma)}$ [TeV] $E_h^{(\gamma)} \geq 4$ TeV	Halo	Alignment by criterion $\lambda_4 \geq 0.8$
LoLiTa	386	6140	31	699	+	+
Pb-45	312	4574	44	1055	+	+
Pb-28	195	3069	59	824	+	+
Pb-3703	180	2559	23	690	+	—
Pb-53	120	2071	44	727	+	—
Pb-8	192	1964	33	621	+	—
Pb-6	91	1521	44	816	+	+
Pb-54	111	1291	30	336	—	—
F73-9	76	949	11	297	—	+
Pb-20	61	897	22	637	+	+
Pb-3704	47	890	7	352	+	—
Pb-6012	48	668	4	53	+	+
Pb-2	60	752	3	130	+	—
Pb-2105	63	687	5	56	—	+
Pb-6013	58	794	12	188	+	—
Pb-58	75	625	23	1086	+	—
Pb-4711	29	575	3	144	—	—
Pb-5901	47	501	2	71	+	—
Pb-2201	35	390	12	125	—	+

Figure Captions.

Fig.1 Structure of the most-used deep lead chamber of 60 cm thickness from Pamir Experiment.

Fig.2 An example of the target diagram with energy distinguished cores for the event with alignment (the family Pb-6). $\lambda_4 = 0.95$. Figures in the plot stand for energy in TeV (already multiplied by 3 for hadrons).

EDC: $\bigcirc$ is the halo of electromagnetic origin;

$\bullet$ is the hadronic halo;

$\oplus$ are the high energy hadrons;

$\cdot$ are the family gamma-quanta;

$+$ are other hadrons of the family.

Fig.3 Dependence of the fraction of families with alignment on total gamma-component energy of an event ΣE_γ.

N_{total} is the total number of families in a given energy range;

N_{align} is the number of families with alignment in the same energy range

a) considering 3 energy distinguished cores (EDC) in each family;

b) considering 4 EDC in each family;

c) considering 5 EDC.

Experiment: ■ is for Pb-chamber data; □ is for C-chambers of the Pamir Joint Experiment (data bank of Waseda University); □ is for the estimate of probable result for Pb-chambers having the reduced thickness equivalent to C-chambers one.

Simulations: – – – – – is for the artificial families by quasiscaling model without any special asymmetry. - - - - - is for randomly incident objects.

Fig.4 Dependence of the fraction of families with alignment on the hadron number N_h in a family.

a), b), c) are for consideration of 3, 4 and 5 EDC in each family (see captions in Fig. 3).

Fig.5 Dependence of the fraction of families with alignment on the number of energy distinguished cores (EDC) under consideration in each family.

For N_{total}, N_{align} see captions in Fig.3,

- - - - - is for the model simulation.

Experiment: ■ is for the families from deep lead chambers with $N_h > 30$. • is for the families from deep lead chambers with $N_h = 1 - 3$. △ is for accelerator data at $E_0 =$ 250 GeV (experiment NA22 at CERN, π-Au interaction).

Fig.6 The distribution of energy fractions over the most energetic 4 cores in a family.

Experiment with deep lead chambers:

■ is for families with $\Sigma E_\gamma > 500$ TeV,

• is for those with $\Sigma E_\gamma = 100$–500 TeV.

Simulations by quasiscaling MSF-model [10].

- - - - - - is for artificial families with any ΣE_γ;

——— is for secondaries just in interaction at $E_0 = 10^{15}$ eV.

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